Naval Submarine Medical Research Laboratory

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Evaluation of the Stereo Optical Co. Farnsworth Lantern (FALANT) Color Perception Test: A Specification and Performance Comparison with the Original FALANT

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Naval Medical Research and Development Command
Research Work Unit No. 64771 0933.002-5405

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SUMMARY PAGE

THE PROBLEM

To validate a cost-saving prototype version of the FALANT using laboratory measures of the colorimetric qualities of the stimulus lights, laboratory tests of environmental aging effects on the stability of the color quality of the plastic filters in the new version, and performance tests using various types of color vision defective subjects.

FINDINGS

The Stereo Optical prototype met the major photometric tests for color and luminance of the stimulus lights. The environmental stability tests indicated that the quality of the stimulus lights would remain stable over time under conditions more severe than they are likely to be subjected. Finally, side-by-side pass/fail performance tests between the original and prototype lanterns using 78 color vision defectives and 20 color vision normals produced results that were highly consistent with each other. This study shows that, to a high degree of probability, the Stereo Optical prototype version of the FALANT, as tested, is a valid substitute for the original FALANT.

APPLICATION

The Stereo Optical Co. version of the Farnsworth Lantern Color Perception Test should provide the Navy a cost effective alternative to the original FALANT. It is recommended that the use of the Stereo Optical Co. FALANT be approved as modified for this test and evaluation, and that the Stereo Optical Co. be required to quality control the luminance and chromaticity of the FALANTs it produces.

ADMINISTRATIVE INFORMATION

This study was conducted at the Naval Submarine Medical Research Laboratory under Naval Medical Research and Development Command Research Work Unit No. 64771 0933.002-5405, Evaluation of the Stereo Optical Co. Farnsworth Lantern (FALANT) Color Perception Test: A Specification and Performance Comparison with the Original FALANT. The manuscript was submitted for review on 26 May 1998, approved for publication on 16 June 1998, and designated as NSMRL Report No. 1209. The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Department of the Navy, the Department of Defense, or the United States Government.

Abstract

The Farnsworth Lantern color perception test (FALANT) has been the U.S. Navy's test for color vision since 1954. It is a reliable and an easy to administer test that separates those with good color vision from those who cannot make accurate color judgments. With the need to purchase additional lanterns while minimizing the cost, the Defense Personnel Support Center sought a less expensive alternative to the original lantern manufactured by the Macbeth Munsell Corp. The Stereo Optical Co. submitted to the Navy a prototype version for examination using less expensive plastic, rather than glass, filters. NSMRL was selected as the Navy's test facility and purchased three prototype lanterns from the Stereo Optical Co. for thorough examination. The colorimetric qualities of the lanterns' stimulus lights were measured and the color filter combination adjusted by the Stereo Optical Co. until the major color and luminance requirements were met. A second Navy laboratory was contracted to perform physical tests on the plastic color filters to assess the effects of environmental aging due to heat, humidity, and tungsten light exposure. Negligible aging effects were found. Finally, 20 color vision normals and 78 color vision defectives were tested on both the original version and the Stereo Optical Co. prototype lantern, and additional tests were administered that assessed type and degree of color vision defect. Pass/fail scores and error scores for the various categories of color vision defectives were highly similar for both lanterns. Within the context of the testing administered (for example, assuming no change in the manufacture of the lanterns, using the same lamps and filter combinations), it is highly probable that the Stereo Optical prototype version of the FALANT will perform as well as the original FALANT. The Stereo Optical Co. version of the Farnsworth Lantern Color Perception Test should therefore provide the Navy a cost effective alternative to the original FALANT. Recommendations are made to: (1) approve the Stereo Optical Co. FALANT as modified for this test and evaluation, and (2) require the Stereo Optical Co. to quality control the luminance and chromaticity of the FALANTs it produces.

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Evaluation of the Stereo Optical Co. Farnsworth Lantern (FALANT) Color Perception Test: A Specification and Performance Comparison with the Original FALANT

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The Farnsworth Lantern color perception test was developed at the Naval Submarine Medical Research Laboratory[1] (NSMRL) and has been the U.S. Navy's test for color vision since 1954 (Figure 1). The FALANT is also currently used by the Army, Air Force, the Coast Guard and Merchant Marine Academies, and, when available, by the FAA as their final validating color vision test. Its purpose is to provide a reliable and easy to administer test that separates persons with normal color vision and very mild degrees of red (protan) or green (deutan) color vision deficiencies from those with color deficiencies so severe that they would have problems performing tasks that require good color vision. A third type of color defective, the blue defective (tritan), is not addressed here due to its extreme rarity[2] of fewer than one in 20,000. Tritans do not confuse red and green.

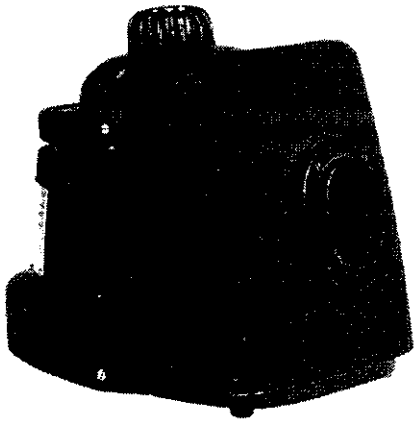

Figure 1. The original Macbeth Corp. version of the FALANT.

The FALANT presents combinations of red, green, and white lights two at a time, one above the other, and the subject simply has to name the colors correctly. The test is given in a normally lighted room. Starting with a red-green or green-red combination, all nine pairs of lights are presented in random order for about two seconds each. The subject, stationed eight feet from the lantern, names the colors of the lights, top color first. An error is miscalling one or both colors of the light pairs. If no errors are made on this first run, the subject is passed. If any errors are made, this run is discarded and two more complete runs of the nine pairs are presented. The error scores for the last two runs are then averaged; if the average is more than one error per run, the subject is failed. If the average is one error or fewer, the subject is passed.

Passing the FALANT is required for most submariner, aviator, and diver ratings, electronics technician, submarine line officers, and others.[3] The pseudo-isochromatic plates (PIPs) are designed to pass only those with normal color vision, and fail *all* color defectives, which comprise about 10% of the male population and 0.5% of females. The FALANT, by passing not only normals, but mild color defectives as well, makes several additional percent of the male population available to serve in these rates. Studies have proven that the original version of the FALANT, manufactured under strict quality control by the Macbeth Corp. (now the Macbeth Munsell Corp.),

Newburgh, NY, has been eminently successful in achieving its purpose.[4,5] A study has also shown that the original FALANT has maintained its diagnostic consistency over many years of continuous use in the field.[6] The FALANT is currently in use at Armed Forces Examining Stations, Recruit Training Commands, military medicine clinics, and other facilities throughout the world.

After many years of useful service, the original FALANTs (Federal Stock No. 6515-299-8587)[7] have been wearing out. In the intervening years since the last procurement was made, the cost of new units has risen dramatically. The Defense Personnel Support Center (DPSC), Philadelphia, PA (now the Defense Supply Center Philadelphia) wished to purchase a number of replacement lanterns, but at a lower cost. During 1992, Stereo Optical Co., Inc., of Chicago, IL, manufacturer of visual test equipment, developed a prototype FALANT of its own design and constructed of materials different from the original specification. Although it presents the same pairs of red, green, and white lights as the original, the prototype provides a reduced cost by employing colored plastic film rather than glass filters. It therefore does not meet the construction requirements as listed in the Military Medical Purchase Description. This prototype was examined at the Naval Aerospace Medical Institute (NAMI), Pensacola, FL, and at NSMRL during mid-1992.

In late 1992, the Staff Director, Defense Medical Standardization Board (DMSB), Fort Detrick, Frederick, MD requested the establishment of a FALANT Special Task Force, comprised of Navy optometrists and color vision experts from NAMI, NSMRL, and the Naval Aerospace Medical Research Laboratory to determine whether this new version of the lantern was comparable to the original.[8] This Task Force met at NAMI in January 1993 to discuss evaluating the Stereo Optical Co. FALANT. The results of that meeting were presented in a letter to the Staff Director, DMSB,[9] outlining the colorimetric, physical, and performance tests that should be done to ensure comparability between the two lanterns. The letter also stated that NSMRL should be the facility to evaluate the prototypes, due to its long history in the development of the FALANT and color vision testing in the Navy. It further stated that the manufacturer should submit production samples for quality assurance tests and provide certification that each unit was tested and that it conformed to specifications.

Also in January 1993, DPSC published a solicitation for proposals to supply FALANTs in the *Commerce Business Daily.*[10] The only interest shown toward this solicitation was from the Macbeth Munsell Corp. (the original manufacturer) and the Stereo Optical Co.[11]

In July 1993, a proposal was submitted by NSMRL to the Naval Medical Research and Development Command (NMRDC) for conducting research to determine the validity of the Stereo Optical Co. lantern. In August, NMRDC approved FY94-FY95 funding for the project. In September 1993, NSMRL submitted a purchase requisition to the Stereo Optical Co. for three prototype FALANTs. In

December, the FALANTs were delivered to NSMRL and in January 1994 evaluation began.

Evaluation

Physical Description and Operation

The Stereo Optical Co. prototype FALANT is shown in Figure 2. Inside its housing, made of a reinforced composition material, is a motor driven wheel in which the color filters are mounted, the lamp (No. BLC, 30 watt, 115-125 volt), and electronic components. It has an illuminated On/Off switch on the rear of the housing with an electronic timer to shut off the lantern after 5 minutes of non-use. On the top of the lantern is a rocker switch, which replaces the rotating knob of the original version, for selecting the stimulus pair to be presented; a small circular window with back-illumination to show the operator the stimulus pair selected; a stimulus exposure push button; and a carrying handle. When either side of the rocker switch is pressed, the motor rotates the filter wheel in one direction or the other to vary the stimulus pair to be presented. When the desired stimulus pair is shown in the viewing window, the operator momentarily presses the exposure push button and the lamp comes on behind the filter wheel, displaying the stimulus pair to the test subject for exactly the recommended two seconds. The operator then manually records the response on a score sheet, selects another stimulus pair, and exposes it, until the testing is completed. The specified instructions for operating, administering, and scoring the lantern are mounted on both sides of the case. Though slightly larger, the Stereo Optical prototype lantern weighs considerably less than the original, due to its composition of primarily synthetic materials as opposed to the original version's cast aluminum housing.

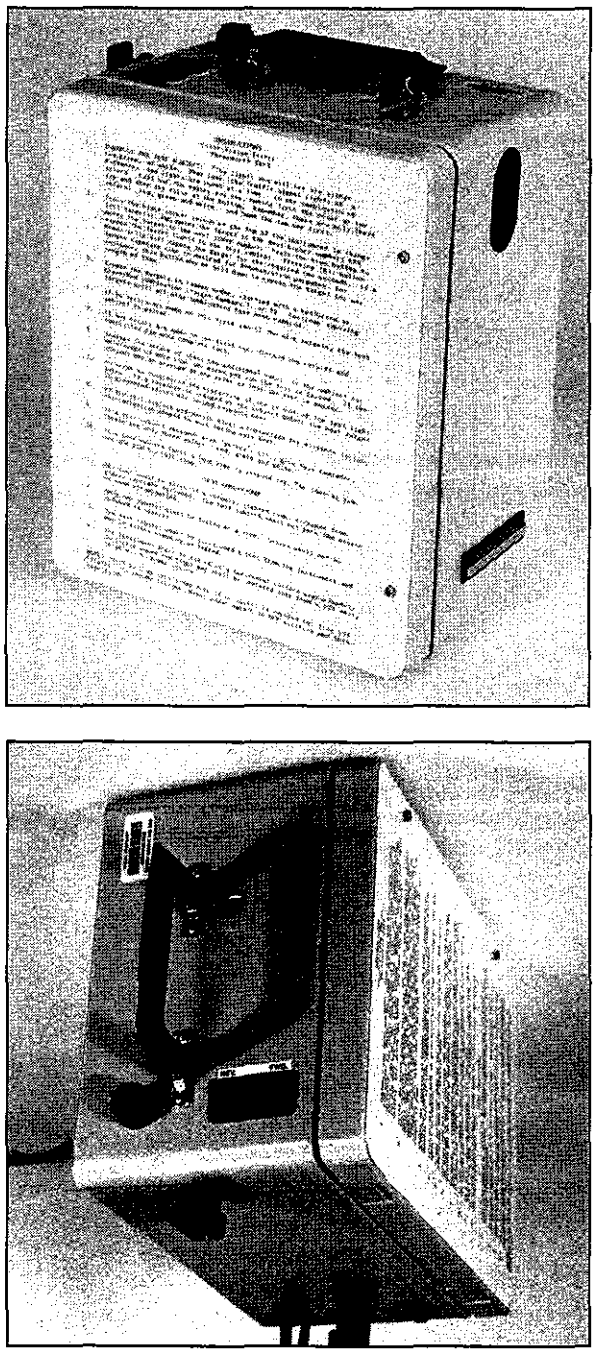

Figure 2. The Stereo Optical Co. prototype version of the FALANT.

The original FALANT has a tilt feature that permits the aperture at the front of the lantern to be pointed at the subject's head, in accordance with the operating instructions. This was to allow the subject to easily see the stimulus lights from either a standing or seated position. The Stereo Optical lantern's rectangular case is set on four small feet with no provision for tilting. When placed on a table of the 30 inches height recommended on that lantern, however, with the subject at the prescribed viewing distance of 8 feet, the stimulus lights can be seen whether the subject is seated or standing. Lack of the tilt feature, therefore, would not normally cause any problem in administering the Stereo Optical lantern.

When the initial prototypes were examined, two deficiencies were noted. The first was that the wheels in which the color filters were mounted were made of clear plastic, so that if rotated while the lamp was on, the apertures were illuminated with bright white light. In subsequent submissions, the filter wheels were made of opaque black plastic, as requested by NSMRL.

The second deficiency was that the rotational position of the color filter wheel could shift out of proper alignment with the apertures at the front of the lantern whenever power to the lantern is off, such as during shipping or handling. Upon notification, Stereo Optical has reportedly changed the design of its FALANT to incorporate an electronic light sensor that automatically causes the motor to rotate the filter wheel to maintain alignment, thus eliminating this problem. This modification has not been reviewed by NSMRL, and, hence, was not a feature of the FALANTs tested.

Photometric Tests

Method

The FALANT employs nine vertical pairs of lights, all the combinations of red, green, and white in the top or bottom position. In one of each stimulus pair, a 50% neutral gray dimming filter is placed to reduce luminance, so that each pair presents a bright and a dimmed light. A neutral diffusing filter is placed over the entire stimulus pair so that the light of each stimulus is spatially uniform. The Military Medical Purchase Description[7] specifies the lights in the FALANT in terms of percent luminous transmittance and 1931 CIE *x,y* chromaticity coordinates, calculated from Illuminant A, from spectrophotometric measurements of the glass filter components that make up the lantern. (Illuminant A is approximated by an incandescent tungsten lamp.) These were chosen to give the desired light output using the prescribed lamp, an Airport Marker Lamp, 115 volt, 40 watt T8 (code 40T8/3), commonly available from Federal Stock at the time of the design of the original FALANT, but no longer available. No values are specified for the resultant output of the 18 light stimuli. Because the Stereo Optical prototype lanterns were constructed in a different manner using combinations of plastic sheet filters, a different method of measurement was adopted. This involved comparing the light output of the prototype with the original.

Photometric tests were done using a recently factory calibrated Photo Research Corp. PR-650 spectroradiometer. All

measurements are referenced to the lanterns being operated at 120 volts AC. First, each of the nine pairs of stimulus lights of two original version FALANTs were measured twice using the PR-650 with a FP-650 fiber optics probe. Mean luminances in cd/m^2 were calculated for each of the six different stimulus lights, the bright and dim of each of the red, green, and white. These means were taken as the target luminance values to be matched by the prototype lantern.

The colorimetric specifications for each color are given by the Military Medical Purchase Description in terms of four-sided boundary areas specified in *x,y* coordinates in the CIE system. These boundaries and their coordinates are shown in Figures 3, 4, and 5. In addition, the neutral filters for the white stimuli and the dimming and diffusing filters have specifications for the Judd Daylight Duplication Index of color neutrality. Stimulus light output of the Stereo Optical prototype lanterns was measured with the PR-650 with an SL-1X close-up lens. Transmittance measurements of the neutral filters were made using the PR-650 with the standard lens.

Three sets of filter wheels were measured, those that initially came in the prototype lanterns (December 1993), a set using plastic Wrattan filters (August 1994), and the final versions using Rosco Laboratories and Kodak color filter materials (May 1995). The first set did not pass the chromaticity requirements; the second and third submissions did pass. Results of these tests were transmitted by NSMRL letter reports to the Stereo Optical Co. in April 1994,[12] November 1994,[13] and July 1995,[14] along with notes on the design and construction of the prototype lanterns. Copies of these letter reports were also sent to the DMSB as notification of progress and results.

Results

The four color filter wheels submitted in May 1995 were installed in the prototype lanterns. All 18 lights (nine pairs) were measured for each of the four wheels. The mean results given here are excerpted from the July 1995 letter report.[14]

Figures 3, 4, and 5 show that all lights, both bright and dimmed, fall within the *x,y* chromaticity limits specified in the Military Medical Purchase Description for the FALANT.

Table 1 shows the mean chromaticity data for the four filter wheels combined. The chromaticity coordinates for like type colors and intensities showed extremely low variability. This indicates that at least for the sample of filters tested, the color reliability is very high. In addition, photometric transmittance measurements were made, also with the PR-650, of two Rosco neutral density filters used in the color wheels, Rosco #3403 N 0.6. One filter sample was submitted by Stereo Optical Co. in May of 1995, the other was purchased by NSMRL over five years ago for another purpose. Measurements showed that the chromaticity coordinates were practically identical between the two samples, and that the spectral transmittance differed by only 1.1%, well within the accuracy limits of the measuring instrument. These results strongly suggest a high level of quality control by Rosco Laboratories, the manufacturer of the filters.

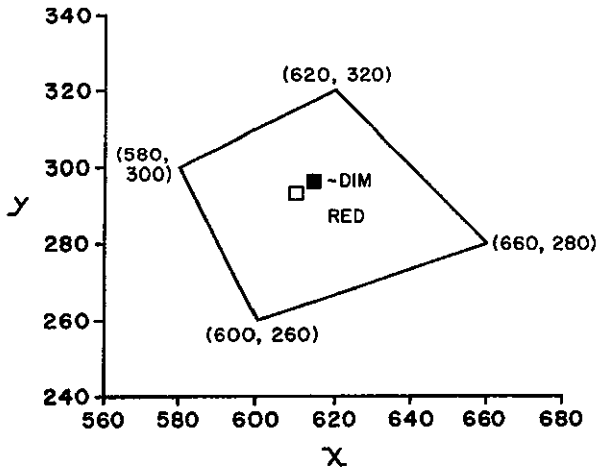

Figure 3. CIE (1931) chromaticity specification limits and plots for Red and Dimmed Red filters.

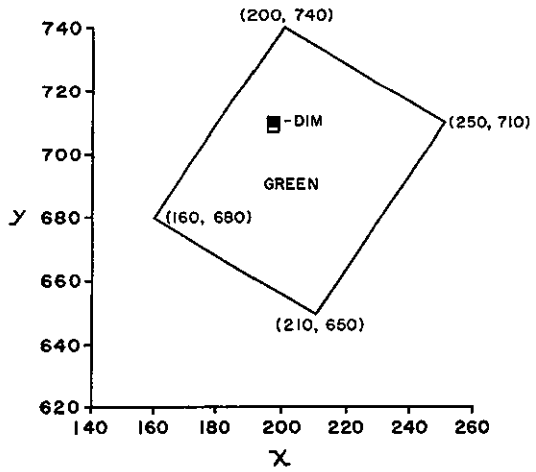

Figure 4. CIE (1931) chromaticity specification limits and plots for Green and Dimmed Green filters.

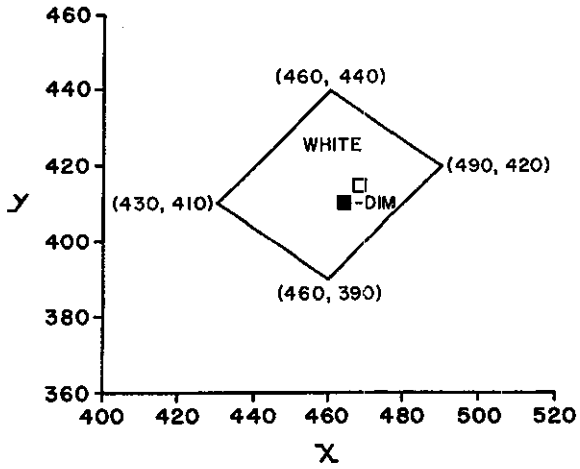

Figure 5. CIE (1931) chromaticity specification limits and plots for White and Dimmed White filters.

Table 1. *Required luminance levels (cd/m^2) and chromaticity and luminance measures from prototype Stereo Optical Co. Farnsworth Lantern Color Perception test, with plastic Rosco color filters of May 1995. Date of test June 1995.*

Color	Required Luminance ±20%	Lantern Filters Stereo Optical Rosco 5/95		
		Luminance	x	y
Red	186	238	.610	.293
Dimmed Red	93	114	.615	.296
Green	136	159	.197	.709
Dimmed Green	68	89	.197	.710
White	160	213	.468	.414
Dimmed White	80	96	.464	.410

Note: Luminance, in candelas per square meter (cd/m^2), and chromaticity coordinates, *x* and *y*, are calculated for Illuminant A. Specifications for chromaticity are given in Figures 3, 4, and 5.

Table 1 also shows the mean luminance measured for each of the types of lights, as well as the required luminances. As mentioned above, luminances of the stimulus lights are not specified per se in the Military Medical Purchase Description, but are a result of the lamp's output and the combination of filters and diffusers placed in the beam. The required luminances shown, on the other hand, are based on measurements of two original model FALANTs manufactured by Macbeth Corp. and are taken as target values for the Stereo Optical Co. version of the FALANT. Luminances of two of the filter wheels were well within the specified range; these were the filters that were used for the subsequent color vision performance tests. The luminances of the other filter wheels were slightly above specifications, so that the means of all four wheels given in Table 1 appear slightly higher than required. According to Stereo Optical Co.,[15] the higher luminance values are probably due to slight variability in lamp placement in the prototype models, which would not be a factor in the production versions.

The individual neutral (white) and neutral dimming and diffusing filters were tested by NSMRL for neutrality of color using the Judd Daylight Duplication Method (Shortened Form), as required in the Military Medical Purchase Description. This requirement specifies the maximum allowable percentage deviation from a distribution of daylight energy across the visible spectrum. Results are presented in Table 2. The dimming and diffusing filters meet or are very close to specification requirements, but the neutral white N 0.9 filter does not meet the specification. It was left for performance testing with color defective subjects to determine whether this requirement can be waived, in light of the difference in construction and materials between original FALANT and the Stereo Optical prototypes.

Table 2. *Judd Daylight Duplication Index test results, in percent deviation, for Rosco plastic filters. Date of test June 1995.*

Filter	Requirement (%)	Test Results (%)
Neutral Diffusing #117	< 4.0	3.3
Neutral White N 0.9	< 8.0	17.6
Neutral Dimming N 0.3	< 3.0	3.9

Summary of Photometric Tests

It was concluded that the Stereo Optical Co. prototype FALANTs with the Rosco Laboratories plastic filters meet the major colorimetric and luminance requirements as specified in the Military Medical Purchase Description for the FALANT. Initial Stereo Optical Co. samples and the Neutral White N 0.9 did not meet the specifications.

It must be noted here that the quality of a color perception test is limited not only by the test conditions and procedures, but to a great extent by the quality of the stimuli presented by the test. The Stereo Optical Co. should therefore be required to quality control the luminance and chromaticity of the FALANTs it produces.

Environmental Stability Tests

Method

It has been established that the light characteristics of the original version of the FALANT, which uses glass filters, are extremely stable over decades of time.[6] To assess the long term transmittance stability of the filters used in the Stereo Optical prototype under accelerated conditions of heat, humidity, and tungsten light exposure, a contract was established with the Materials Analysis Laboratory of the Naval Undersea Warfare Center (NUWC), New London Detachment to conduct environmental stability testing.

Two of the filter wheels tested previously,[14] designated filter wheels "D" and "E," were selected for environmental stability testing, with the data shown in Figures 3 through 5 and Table 1 to be used as baselines for spectral transmittance stability. The two filter wheels and the individual component filters were submitted to NUWC for environmental exposure. NUWC also conducted various analyses and measurements on the component filters before and after the environmental exposures. Twelve individual filters were tested: Rosco Laboratories # 111, 116, 117, 118, 122, 339, 871, 3402, 3403, 3404, 3415, and 2556 (Kodak). NUWC has prepared a complete technical report of its results on testing the individual filters.[16] After exposure, the filter wheels were returned to NSMRL for retesting of the spectral quality. A summary of the tests and the results follows.

Environmental Exposures. The assembled filter wheels and filter components were subjected to the following conditions as listed here:

Filter wheel "D" was incubated for 34 days at 38°C (100°F) (ambient temperature exposure).

Filter wheel "E" was incubated for 34 days at 70% relative humidity over a saturated sodium chloride solution at room temperature (ambient humidity exposure).

One each of the 12 component filters was subjected to the ambient temperature exposure.

One each of the filters was subjected to the ambient humidity exposure.

One each of the filters was subjected to visible light radiation. Each filter was mounted 85 mm (3.75") from a 40 watt tungsten lamp used in the FALANT, approximately the distance it would be in actual use. The duration of the component filter exposures was a minimum of 72

continuous hours. This is equivalent to about 13,000 administrations of all nine light pairs of the test.

Test Procedures. For each sample, the same test was conducted both before and after the environmental exposure, as described below.

NSMRL

Chromaticity and luminance tests of FALANT lights were conducted on filter wheels "D" and "E." The filter wheels were installed in Stereo Optical Co. prototype lanterns, and each of the nine pairs of lights was then measured in the manner described earlier.

NUWC

Fourier Transform Infrared Spectroscopy (FT-IR) and Ultraviolet and Visible (UV/VIS) Spectrophotometry tests were conducted on component filters. These tests were used to identify suitable spectroscopic properties and molecular structure of the dyes embedded in the filters that can be used to evaluate the aging behavior of the filters.

Results

NSMRL

For the filter wheel "D," exposed to prolonged high ambient temperature, and filter wheel "E," exposed to prolonged high ambient humidity, comparison of the data before and after their respective environmental exposures showed only small and negligible differences, all within the accuracy of the instrument and measurement techniques. Chromaticity coordinates in x,y typically varied ± .002, with a maximum difference of .004. If the x,y chromaticity coordinates were plotted on the CIE Chromaticity Diagrams as given in Figures 3 through 5, the points before and after exposures would virtually overlap. Luminance values in cd/m^2 typically varied ±3%, with a maximum difference of 6.3%. It is concluded that exposure of the filter wheels to those environmental exposures used here made no appreciable change in the light quality of the prototype lanterns. It is therefore highly unlikely that the light quality of the lanterns would change appreciably over long periods of time due to the effects of visible light, high heat, and high humidity.

NUWC

For the tests conducted by NUWC on the individual filter materials, graphs in the technical report show the infrared spectrum and the ultra-violet/visible spectrum of each filter both before and after the environmental exposures. The "before" and "after" curves were virtually identical for each of the 12 filters. To quote from the technical report[16] regarding the infrared spectra:

> "Since the spectra are, for the most part, identical, the polymers are most likely unaffected by the temperature, humidity, and light exposure during incubation.
>
> "Similarly, the UV/VIS spectra recorded after the incubation times were identical. ...Again, there are no observable differences. This observation strongly suggests that the dyes are stable and do not

undergo chemical changes or migration from the plastics during incubation."

Summary of Environmental Stability Tests

The following is a quote from the NUWC technical report:

> "In conclusion, the plastic filters manufactured by Rosco Labs display long-term stability to heat, humidity, and visible light. Although the conditions employed in this study were not 'drastic,' they do represent realistically the conditions of long-term usage and storage of the plastic filters. The incubation times selected for this study were somewhat arbitrary. Still, they were sufficiently long to be able to conclude that the temperature, humidity, and light conditions used in this study were not sufficient to degrade the transmission properties of the plastics."

The Stereo Optical Co. prototype FALANTs with the Rosco Laboratories plastic filters have therefore met the environmental exposure stability tests imposed on them, leading to the conclusion that quality of the stimulus light in the lanterns would remain stable and the test would retain its diagnosticity over a long period of time. These results were forwarded to the Stereo Optical Co. and to the DMSB in an NSMRL letter report of 8 April 1996.[17]

Color Vision Performance Tests

Method

Subjects. Volunteers were recruited through screening, referrals, and solicitations. A total of 98 subjects were tested, 95 men and 3 women. Twenty-one of the subjects were tested in the Vision Department of NSMRL between June 1996 and March 1998. Seventy-seven subjects were tested at the Great Lakes Recruit Training Command (GLRTC), Chicago, IL, during the periods 14-18 April 1997 and 07-11 July 1997. Of the total tested, 88 were military and 10 were civilians. Because most of the subjects were naval recruits, the predominant age range was 18 to 20 years, although several civilians were over 40.

All subjects were told that except for the original version FALANT test as required by GLRTC, additional testing was strictly voluntary. If the subject was willing to undergo additional testing, a voluntary consent form was administered and further testing was begun.

The NSMRL Color Vision Test Battery. The test battery, developed by Farnsworth,[18] consists of a selected set of American Optical Co. pseudo-isochromatic plates (PIP), the Farnsworth Tritan Plate, the Farnsworth Lantern, a hand-held anomaloscope, and the Farnsworth Dichotomous-15 (D-15) button test. Subjects are classified as to degree of defect as shown in Table 3; the Severe category included dichromats (protanopes and deuteranopes). The hand-held anomaloscope is used to distinguish among normals and mild and moderate protans and deutans, and the D-15 distinguishes severe

and dichromatic protans from severe and dichromatic deutans. No tritans were found in this study.

Table 3. *Classification scheme for NSMRL Color Vision Test Battery.*

Classification	Test		
	PIP	FALANT	D-15
Normal	Pass	Pass	Pass
Mild	**Fail**	Pass	Pass
Moderate	**Fail**	**Fail**	Pass
Severe	**Fail**	**Fail**	**Fail**

Procedure. Subjects tested at NSMRL were given the test battery individually in the Color Vision Testing Laboratory, with the conditions required for each test's proper administration strictly adhered to.

At GLRTC, color vision testing was conducted so as to interfere as little as possible with the ongoing normal physical examination routine. This necessitated administering the FALANT tests in a group setting, contrary to the instructions on the FALANT. Recruits were first screened in a group testing room using eight pseudo-isochromatic plates attached to room dividers and illuminated with the room's normal overhead fluorescent lighting. Any recruit who misread one or more plates was administered the voluntary consent form, tested on the original FALANT, and, if willing, also on the prototype version FALANT, again in the same group testing room. The order in which the two lanterns were given was alternated over days, so that approximately half the subjects were tested on the original FALANT first and the other half tested on the prototype first, to eliminate an order effect. The subjects were then directed to a separate room in which the remainder of the NSMRL Color Vision Test Battery, including the PIP, was administered on an individual basis.

In all cases, after the test battery was completed and scored, the results were discussed with the subject and an explanation of the tests and of basic color vision facts were given.

Results

Twenty color vision defective subjects, including 2 women, were identified and tested. Of the total, due to time constraints, two color defective subjects were not administered the entire test battery and therefore could not be completely classified as to type and degree of defect. All subjects were administered both lanterns, however. Because the original FALANT is the standard by which to judge the prototype, classification was based on performance on the original. The breakdown of the 76 color defective subjects who were classified by type and degree is given in Table 4. This shows that at least some of all types and degrees of color defectives were represented in the results. Since the sample of subjects was preselected, the relative percentages are not representative of those in the general population.

Table 4. *Number and percentage of color vision defective subjects by type and degree of defect.*

Type		Degree			Total
		Mild	Moderate	Severe	
Protan	n	2	9	18	29
	Percent	2.6%	11.8%	23.7%	38.2%
Deutan	n	10	15	22	47
	Percent	13.2%	19.7%	28.9%	61.8%
Total	n	12	24	40	76
	Percent	15.8%	31.6%	52.6%	100.0%

Table 5 compares pass/fail performance of the original and the Stereo Optical FALANTs for the 78 color defectives. Summing the Pass/Fail diagonals in this table shows that there was 92.3% agreement between the two versions of the FALANT, that is, of the 78 color defectives, 72 (92.3%) were classified the same by both lanterns; 6 (7.7%) were not. Of these six, four passed the original and failed the Stereo Optical lantern (all mild deutans), while two who failed the original passed the Stereo Optical lantern (one mild deutan and one moderate protan). Although there is negligible "learning" in repeated testing on the FALANT and extremely high consistency among subsequent tests, it has been occasionally observed that after first experiencing the test, an immediately subsequent test will show an improved score. Whether this is due to learning, being less anxious in the testing situation, being more comfortable with the test itself, or something else, is a matter of conjecture. It is worth noting, however, that in all six cases in which the pass/fail classification between the two lanterns did not agree, the subjects failed the first lantern taken and passed the second. Some of this may be attributable to chance and some to the unusual test condition of a group situation.

In this selected sample, the original FALANT passed 15% (12 of 78) of the color defectives and the Stereo Optical prototype passed 13% (10 of 78). Although these latter numbers are small, they suggest that the Stereo Optical FALANT is, in general, slightly more difficult to pass than the original. Thus, it is a more cautious assessment that errs on the side of safety in color discrimination situations.

Table 5. *Number and percentage of color defective subjects passing and failing the original Macbeth FALANT and the prototype Stereo Optical Co. FALANT.*

Lantern			Stereo Optical Co.		Total
			Pass	Fail	
Original	Pass	n	8	4	12
		Percent	10.3%	5.1%	15.4%
	Fail	n	2	64	66
		Percent	2.6%	82.1%	84.6%
Total		n	10	68	78
		Percent	12.8%	87.2%	100.0%

The kappa statistic,[19,20] a measure of classification agreement between two tests, was computed on the pass/fail data in Table 5. The value of kappa for our sample was .683. This value indicates that the proportion of agreement beyond statistical chance between the original and the Stereo Optical FALANTs was very good, consistent with the 92.3% agreement we found by actual test. The kappa value was significantly different from zero at $p < .001$.

In addition to the 78 color defectives, 20 subjects were tested on the NSMRL Color Vision Test Battery and were classified as having normal color vision. All passed the PIP test and the tritan plate test, matched within the normal range on the anomaloscope, and made zero errors on both the original and Stereo Optical versions of the FALANT. It has long been observed that color vision normals make virtually no errors on the FALANT, and this held true for the present sample.

Note that the above kappa measure was computed on only color defectives. This is the most stringent and meaningful use of this measure. If normals, who never fail the FALANT, had been included in this measure, the value of kappa could have been

deceptively driven close to 1.0, since the number of subjects correctly classified would have approached 100%.

An additional statistic was computed on the pass/fail performance of color defective subjects given in Table 5, the McNemar test for correlated proportions.[21] For this test, $\chi^2(1,N=78) = .167, p > .10$, showing that there was no significant difference in the true distribution of outcomes of the original and Stereo Optical Co. FALANTs.

Table 6 compares the mean number of errors made by each type and degree of color vision defect on each lantern. It can be seen that the scores on the two lanterns are very similar for each category of defect.

Table 6. *Mean error scores by type and degree of color vision defect on original FALANT and Stereo Optical prototype FALANT. Number of subjects in each category are given in parentheses; N = 78.*

Degree of Defect	Type of Defect					
	Protan			Deutan		
	n	Original	Stereo Optical	*n*	Original	Stereo Optical
Mild	(2)	0.5	0.0	(10)	0.2	0.9
Moderate	(9)	3.6	3.2	(15)	3.9	3.9
Severe	(18)	5.6	5.8	(22)	6.4	6.3

Another way of comparing the performance of the original with the Stereo Optical prototype FALANT is by looking at the correlation of the number of errors of the two instruments. The data and their regression line are shown in Figure 6. The product-moment correlation was a reasonably high $r = .823$, significantly different from zero at $p < .001$, $df = 76$. The strength of the relationship of the two lantern scores, or the coefficient of determination, was $r^2 = .678$, which means that nearly 70% of the variance in the error scores of the Stereo Optical lantern was accounted for by the scores on the original FALANT. This is another indication that it is likely that the error scores on the Stereo Optical lantern will be similar to those on the original version for various types and degrees of color defectives. In other words, both lanterns appear to perform similarly.

The regression equation's *y*-intercept was 0.96, significantly different from zero, $t(76) = 2.99, p < .01$. This indicates that for the sample tested, in the low error score range, color defectives make slightly more errors on the Stereo Optical version than the original. The slope of the line, 0.80, indicates that as the error scores increase on the original FALANT, they increase similarly on the Stereo Optical Co. prototype. The standard error of the estimate for this linear regression is 1.36 errors, which is the standard deviation of the Stereo Optical lantern scores about the regression line. This is another measure of the amount of error in the correspondence between the original FALANT error scores and those of the Stereo Optical version.

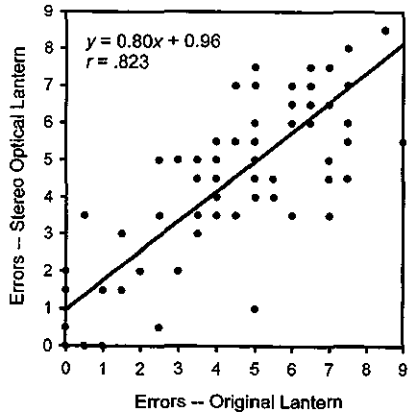

Figure 6. Scatter plot of errors by color vision defectives on the Stereo Optical prototype lantern vs. errors on the original FALANT, with linear regression equation and line fit to the data. N = 78.

Summary of Color Vision Performance Tests

For the sample of 78 color vision defectives tested, pass/fail performance of the Stereo Optical Co. prototype version of the FALANT was very similar to that of the original Macbeth Corp. FALANT. In percentages, 92.3% of the color defectives and 100% of the normals received the same pass/fail classification on both lanterns. Of the 6 color defectives (7.7%) whose classifications were in disagreement, 4 passed the original version and failed the Stereo Optical prototype version, suggesting a slight bias towards being more conservative for the Stereo Optical lantern. Mean lantern error scores for all categories of color defectives were very similar for both lanterns. All color vision normals passed both lanterns with no errors. It appears that the neutral filter discrepancy from the Judd Daylight Duplication Index specification mentioned above is not an important factor in the performance of the Stereo Optical Co. lantern.

As noted above, the conditions for administering most of the lantern tests were not as prescribed. At GLRTC, the lanterns were given in a large, somewhat noisy, open room among many other fellow recruits, hospital corps personnel, and superior petty officers. This would tend to make the scores on both lanterns more variable, due to the subjects' distraction and possible nervousness and embarrassment in the presence of others. It is therefore reasonable to assume that greater correspondence between the scores on the two versions of the FALANTs would have been obtained if the lantern tests were administered individually in a private setting, as prescribed.

Furthermore, test-retest reliability for any test instrument is rarely perfect. In a study of 500 color defectives tested at NSMRL, 3.4% received different pass/fail classifications on retest using the exact same FALANT under laboratory test conditions.[4] Thus, the results obtained in the present study are quite reasonable.

Usability of the Stereo Optical Co. FALANT

Comments on the usability of the Stereo Optical version of the FALANT were solicited from the four test administrators who used both lanterns to a considerable extent during the course of this study. Their comments were in agreement in several respects. First, because the window that displays the selected stimulus light pair is located on the top of the lantern, the operator cannot see the selected lights except by viewing from above. The selection is not visible from the rear or sides of the lantern, a specific feature of Farnsworth's original design. This makes it difficult for the operator to administer the lantern from a seated position, typical of test administration conditions.

A second comment was that using the rocker switch to slew the filter wheel to the desired position took a little longer than spinning the knob on top of the original version. Over time, however, the electronic selection on the Stereo Optical version may prove more trouble free than the mechanical selector knob on the original, since the latter has often had problems with the detent wheel inside the housing moving out of adjustment or cracking so that it could not hold its adjustment. This problem caused misalignment of the stimulus lights in the viewing aperture, often to the point of

complete loss of visibility.

A feature of the Stereo Optical lantern of which operators were unanimously in favor was the automatic 2-second timer on the light exposure switch. The operator need only press the button momentarily and the stimulus lights are exposed for the correct amount of time, making it easier for the operator and making the test more consistent.

Another desirable feature of the Stereo Optical version is the large, easy to read instructions on each side of the lantern. This should help ensure proper administration of the color vision test with this lantern.

In summary, the usability of the Stereo Optical version of the FALANT was tested and evaluated and, while it has minor shortcomings, it also has some desirable features not found on the original version. Extended use in the field will tell whether the Stereo Optical version proves as durable under use as the original FALANT. The construction of the Stereo Optical version appears adequate to withstand prolonged use in the clinical setting for which it was designed.

General Conclusions

The Stereo Optical Co. prototype version of the Farnsworth Lantern Color Perception Test was assessed in comparison with the original Macbeth Corp. version. The Stereo Optical prototype met the major photometric tests for color and luminance of the stimulus lights. The environmental stability tests indicated that the quality of the stimulus lights would remain stable over time under conditions more severe than they are likely to be subjected. Finally, side-by-side pass/fail performance tests between the original and prototype lanterns using 78 color vision defectives and 20 color vision normals showed results that were highly consistent with each other.

Test results therefore show that, to a high degree of probability, the Stereo Optical prototype version of the FALANT, as tested, will perform as well as the original FALANT.

As stated in Reference 9, the manufacturer, Stereo Optical Co., should be required to provide certification that their production lanterns were tested and met the chromaticity standards as given in the Military Medical Purchase Description[7] and luminance standards as given in Table 1 of this report.

With adherence to these standards, and with the changes to the prototype (opaque filter wheels and a filter wheel alignment provision, as discussed in the Physical Description and Operation section), the Stereo Optical Co. version of the Farnsworth Lantern Color Perception Test should provide the Navy a cost-effective alternative to the original FALANT.

Recommendations

1. Approve the use of the Stereo Optical Co. FALANT, as modified for this test and evaluation of spectral qualities and stability, similarity to clinical results obtained with the original FALANT, and usability.

2. Require the Stereo Optical Co. to quality control FALANT luminance and chromaticity.

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The Farnsworth Lantern color perception test (FALANT) has been the U.S. Navy's test for color vision since 1954. It is a reliable and easy to administer test that separates those with good color vision from those who cannot make accurate color judgements. With the need to purchase additional lanterns while minimizing the cost, the Defense Personnel Support center sought a less expensive alternative to the original lantern manufactured by the Macbeth Munsell Corp. The Stereo Optical Co. submitted to the Navy a prototype version for examination using less expensive plastic, rather than glass, filters. NSMRL was selected as the Navy's test facility and purchased three prototype lanterns from the Stereo optical Co. for thorough examination. The colorimetric qualities of the lanterns' stimulus lights were measured and the color filter combination adjusted by the Stereo Optical Co. until the major color and luminance requirements were met. A second Navy laboratory was contracted to perform physical tests on the plastic color filters to assess the effects of environmental aging due to heat, humidity, and tungsten light exposure. Negligible aging effects were found. Finally, 20 color vision normals and 78 color vision defectives were tested on both the

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original version and the Stereo Optical Co. prototype lantern, and additional tests were administered that assessed type and degree of color vision defect. Pass/fail scores and error scores for the various categories of color vision defectives were highly similar for both lanterns. Within the context of the testing administered (for example, assuming no change in the manufacture of the lanterns, using the same lamps and filter combinations), it is highly probable that the Stereo Optical prototype version of the FALANT will perform as well as the original FALANT. The Stereo Optical Co. version of the Farnsworth Lantern Colr Perception Test should therefore provide the Navy a cost effective alternative to the original FALANT. Recommendations are made to: (1) approve the Stereo Optical Co. FALANT as modified for this test and evaluation, and (2) require the Stereo Optical Co. to quality control the luminance and chromaticity of the FALANTs it produces.